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FIVE FOLD CHECK OF URANITE AGE?

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The object of this paper is to show that with sufficient physical and chemical data it will be possible to have more than a five fold check on the age of a mineral disintegrating like uraninite, and that even now the range of possible age consistent with the data is limited.

That atoms of uranium and thorium disintegrate is now well known. The general theory has been treated in a popular way by A. Holmes¹ and by myself,² in scientific detail by Hevesy, Paneth, and Lawson,³ and in Bulletins 51 and 80 of the National Research Council, so that I need only briefly to outline certain facts to which I wish especially to refer.⁴

If one places a glass plate slightly sticky with castor oil, having a film of a sensitive zinc sulphide on its underside, over a mineral containing uranium and thorium, one will see in the dark with a pocket lense flashes like fireflies.⁵ These are due to particles of helium (less an electron), known as alpha particles, thrown off by the explosion of atoms of the radioactive elements, which strike the film of zinc sulphide and make it glow. One milligram of uranium, which weighs as much as 3.7 mm. square of fair weight letter paper will throw off 94 flashes a second. Of these 23.7 seem to be due to the explosion of uranium I and II, and most of the others to the successive changes (Bulletin 80, pp. 133-136) through ionium,

¹ Age of the Earth, Harper Bros.

² *Scientific Monthly*, April, 1931; *Scientific American*, Feb., 1930, p. 111.

³ Radioactivity. Oxford Press.

⁴ Since the presentation of this paper (December 29, 1933), I have had the advantage of an extensive mimeographed report by Prof. A. C. Ruark, and of seeing the recent papers and correspondence with O. B. Muench, J. P. Marble, H. S. Spence, T. R. Williams, H. R. Bishop, C. S. Piggot, W. D. Urry, and A. von Grosse; all of which has been used in the final revision.

⁵ Several minutes are needed to sensitize the eye in the evening, ten minutes or more in the daytime.

radium, etc., to a stable lead. But according to A. von Grosse⁶ for every 100 atoms which explode and pass through uranium, radium, etc., to lead, there are four which pass through protactinium and actinium. In the former case he gives final lead the atomic weight $205.96 \pm .02$,⁷ in the latter $207.010 \pm .01$. According to von Grosse this proportion is now the same for all minerals⁸ independent of geologic age, geographic origin, thorium or uranium concentration, but he assumes, following Rutherford, that Ur-actinium disintegrates about ten times more rapidly than the atoms which change into ionium so that of course, there was a larger proportion in times past.

The number of atoms of any radioactive element disintegrating seems to depend on the number present, and experiments through many degrees of temperature and atmospheres of pressure in various compounds show no variation. Thus this ratio generally designated as lambda (λ) is characteristic of an element. It may be represented, if dN indicates the number changing in a year and N the number present, as dN/N .

The lambda (λ) for uranium is⁹ about $1.535 (10)^{-10}$ if the year, according to Kovarik, is taken as the unit. Since in a gram of uranium there are about $1/(1.65(10)^{-24}.238)$ atoms, the dN is small enough relative to N to apply the integral calculus formula $\int dN/N = \log. N$, and if t_0 is the time of formation, and N_0 the number of atoms (then), and t the time of observation (at the present), and N the number of atoms at the present, and if U_0 is the weight of uranium at the beginning and U is the weight of uranium at the time of observation, then $U_0/U = N_0/N$. Also $\lambda t - \lambda t_0 = (\log. N - \log. N_0) = -\text{Nat. log. } N/N_0 = -\text{Nat. log. } U/U_0$. But the number of atoms N is $U/1/(1.65(10)^{-24}.238+)$.¹⁰

⁶ *Physical Review*, November 15, 1932, pp. 565-570, with references to previous literature. I wish heartily to thank him for the opportunity to see his paper in advance of its publication in preparing mine.

⁷ But Alter and Baxter find in the Bedford cyrtolite (*J. Am. Chem. Soc.*, **55**, p. 1447, 1933) a lead with the atomic weight of but 205.92, and in the *Physical Review* for January, 16 isotopes of lead and of uranium are reported.

⁸ According to Wildish variable, but always small, and in the papers in the *Physical Review* just mentioned the order of abundance of the isotopes is 206 and 207 or 208.

⁹ 1.471 in National Research Council Bulletin **80**, p. 86; 1.535 in the report of the Committee on the Measurement of Geological Time for 1932.

¹⁰ The weight of 1 hydrogen atom is $1.66(10)^{-24}$ grams, but its atomic weight is more than 1 depending on whether O is taken at 16, as usual, or allowance made for

The original number of atoms is:

$$N_0 = U(1/(1.65(10)^{-24} \cdot 238 +) + Pb(1/(1.65(10)^{-24} \cdot 206 \pm))$$

thus:

$$N_0/N = 1 + Pb \cdot 238/U \cdot 206$$

If the Pb is all Pb produced from Ra then for 206 we should write, according to von Grosse, 205.96. Now the age of the mineral $= t_0 - t = 1/\lambda$ Nat. log. U_0/U , but in place of λ is often written the value of $t_0 - t$ when the uranium is half gone, i.e., $U_0/U = 2$, which is called T , therefore, $T = 1/\lambda$ (Nat. log. $2 = .692$); $T\lambda = .692$. If also, in place of the natural logarithms which are 2.3 as great, we use the decimal logarithms, we have a formula:

$$\text{Age of minerals} = 3.323 T_U \log.(1 + 1.156 \text{ RaG}/U).$$

For thorium there is a similar formula: Age $= 3.323 T_{Th} \log.(1 + 1.115 \text{ ThD}/\text{Th})$.

There are two uncertainties in the calculations, the rate of disintegration of uranium and also what proportion of uranium gives that disintegration of atoms which will turn into radium, and ultimately into RaG (Pb_{206}), and what into other isotopes. Isotopes present in very small quantities may contribute a much larger proportion of the disintegration if they are exploding at a rapid rate.

That the rate of change and disintegration, however, has not widely changed in time is made clear by the halo rings around radioactive particles. The exploding atoms send off alpha particles, helium bullets in minerals which enclose small radioactive particles which are likely to smash up molecules and produce change of color, and do more smashing near the end of their flight, just as a bullet at muzzle velocity will go through a window pane and make a small hole, but toward the end of its flight is likely to shatter the pane.

Each element, moreover, sends its alpha particles off with a velocity which on the average is characteristic of that element. And the more rapidly it explodes, the higher the velocity and the wider the range affected.

Now it appears that the range of these halos in very old rocks is, as Kerr Lawson has shown, nearly identical with those today. However, the rings in halos around radioactive material are deeper and more frequently noted in the older rocks, though they are discharged by heating.

I have found it convenient to refer to the uranium isotope parent of radium as Ur-radium, U_{ra} , and the uranium isotope parent of

the fact that oxygen itself has isotopes and therefore should be given an atomic weight of something like 16.00022.

actinium as Ur-actinium, U_{ac} . We may also have to refer to Ur-thorium and Ur-virginium. It seems certain that Ur-radium is the main isotope U_{238} of which Aston¹¹ says that uranium is composed to the extent of at least 97 per cent. The relative amounts of the isotopes of uranium are not yet certain.¹² The atomic weight found is 238.14 and Elsen¹³ estimated that there should be up to 18 per cent of U_{239} which he considered the parent of the actinium series, and Kirsch¹⁴ suggested similar figures. This is of course inconsistent with Aston's result. On the other hand, von Grosse¹⁵ and Rutherford and Kovarik all depend on Aston and deduce almost negligibly small amounts of Ur-actinium (U_{239}). One thing at least seems certain. The more rapidly Ur-actinium explodes the less of it there is to give the ratio of four actinium atoms to a hundred of radium. Assuming this to be true, and that the radium series ends with Pb_{206} which the work of Baxter and his students practically has proved, and that thorium forms the Pb_{208} , then the actinium series would be responsible for the Pb_{307} , which Aston reports as the next most abundant isotope; and we have five ways of estimating the age: by the formation of $Pb_{206, 207, 208}$, and helium, and if we can from the oxygen estimate the uranium originally present we may compare that with the uranium now present. We will illustrate with the Wilberforce uraninite.

(1) AGE OF WILBERFORCE URANINITE BY UR-RADIUM

Kirsch and I showed that the amount of RaG , i.e., Pb_{206} , can not vary greatly in the Wilberforce lead in view of the amount of lead and the atomic weight of the lead determined. Our Fig. 1, here repeated with additions, shows that our conclusion fits nicely with Aston's¹⁶ estimates of the proportions of lead present.

If, as von Grosse thinks, Ur-actinium disintegrates ten times as quickly as the Ur-radium (Kovarik makes it not quite as fast, $2.7(10)^8$ years), there can be but 0.4% of the Ur-actinium. This leaves the excess of uranium atomic weight over 238 unaccounted for as above mentioned.

The highest amount of Ur-actinium suggested, based on the

¹¹ *Nature*, **128**, p. 725, 1931.

¹² Wilkins, T. R., *Nature*, Oct. 1932, and the *Physical Review*, Jan. 1933.

¹³ *Loc. cit.*, p. 286.

¹⁴ *Radioaktivität und Geologie*, p. 133, 200. See also Western and Ruark.⁹

¹⁵ *Physical Review*, **42**, pp. 42-43, 1932.

¹⁶ *Nature*, **129**, p. 649, 1932.

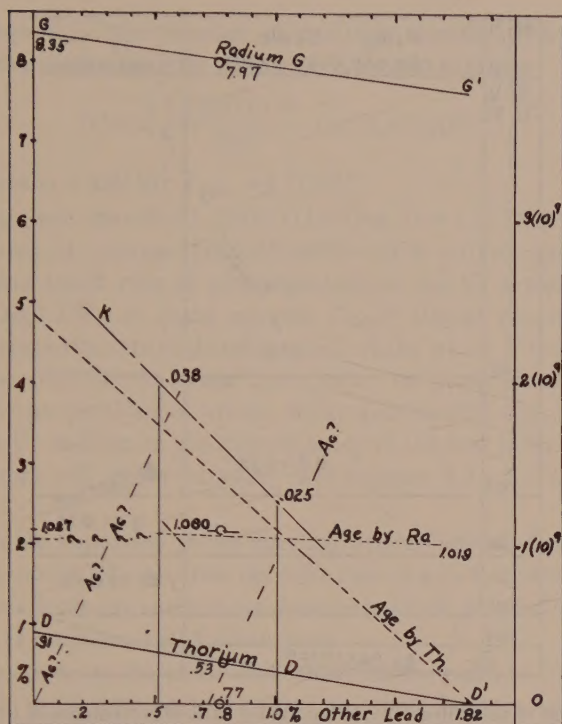


FIG. 1. (From p. 368, Vol. 66, *Proc. Am. Ac. of Arts and Sciences*.) Illustrates the computation of all possible ages of the Wilberforce uraninite consistent with the amount of uranium, thorium, and lead and the atomic weight of the latter. Possible amounts of lead not derived from radium and thorium are laid off as abscissas. Full lines join the tops of the ordinates which show the Radium G and Thorium D that correspond, and the scale is on the left. Lines with dashes show the ages corresponding. Their scale is on the right. In *Nature*, April 30, p. 649, 1932, Aston reports 85.9 of $Pb_{206} = RaG$, 83.0 of $Pb_{207} = AcD$, and 5.8 of Pb_{208} , which implies the percentages shown by the circles, and the age by the circle and dash which have been added to the original figure.

supposition that it is responsible for the excess of the atomic weight of U over 238, is by Elsen.¹⁷ A curve, labelled actinium Fig. 2, is plotted for all possible values of the amount of U_{ra} and the corresponding disintegration, and ages deduced. On the whole the curve shows that a short life and but little of Ur-actinium give an age that fits best the age given by U_{ra} . This latter age comes out much the same, whatever is assumed as to the Ur-actinium and is thus more likely to be correct.

¹⁷ *Receuil des Travaux chimiques des Pays Bas*, Feb. 1932, p. 286.

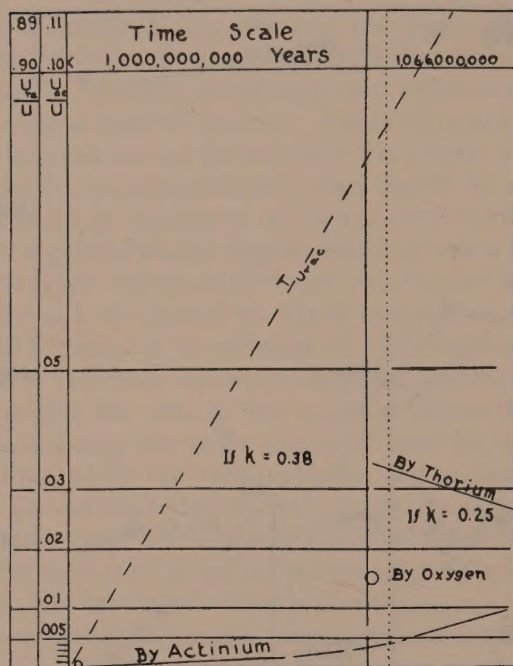


FIG. 2. Age of the Wilberforce Uraninite for various percentages of Ur-actinium: by radium G, short dashes (about 1075 million years); by thorium for various k factors from 0.25 to 0.38; by actinium, long dashes.

Also the half life of Ur-actinium T implied, on a scale reduced ten times. 427 million years fits best.

Obviously the more rapid the distintegration of the Ur-actinium the less will be needed to keep up the present supply of four atoms to 100. If the Ur-actinium decays at the same rate as the Ur-radium 4% would be enough. The rate of decay of Ur-radium is said to be such that its half life is¹⁸ something like $4.3(10)^9$ years. If Ur-actinium is so short lived as to be half gone in $4(10)^8$ years, there would be needed only $(4/43)$ a tenth as much.

If there is 0.004 of Ur-actinium as von Grosse says (p. 568) the Ur-radium is $53.52 (1 - 0.004) = 53.31$. It can not be more than 53.52.

If von Grosse is right that the "activity ratio" (the ratio of distintegration) is four protactinium atoms to 100 radium atoms, then of the present distintegration studied by Kovarik only 96% is due to Ur-radium.

¹⁸ Kirsch and Lane, *Am. Ac. Sci.*, 66, p. 359, 1931.

Consequently, the number of particles thrown off by the .996 Ur-radium of the number noted by Kovarik will be

$$0.96 \times \frac{1.535(10)^{-10}}{.996} \text{ i.e., } 1.473(10)^{-10}$$

which means a half life $T_{\text{Urra}} = 4.7(10)^9$.

The age will then be $(3.323)4.7(10)^9 \log. (1 + 1.156 \times 7.97/53.31)$. In millions of years $= 15600 \times 0.0689 = 1078$ million years. If we take a less rapid rate of disintegration of the Ur-actinium and a greater half life, we must assume T_{Urra}^{19} almost proportionately shorter since the rate of disintegration of the whole U must be kept the same. But in that case there must be more Ur-actinium to make the proportions of atoms disintegrating still 4%, and therefore less Ur-radium in the denominator of the last term, and these two factors will about balance—will balance if $T_{\text{Urac}}:T_{\text{Urra}}$ is large enough.

The table appended shows ages for various assumed proportions of Ur-actinium. *We see from the table that on any hypothesis as to the Ur-actinium the age can not consistently with the physical and chemical data be far from 1070 million years.*

It is clear from the table that whatever the ratio of Ur-actinium assumed, from nothing to 11 per cent, there is only ten to fifteen million years difference in the age as figured by the radium. As we assume more of the Ur-actinium to be still present, its rate of decay must be assumed less and that of the Ur-radium increased so that this partly balances the greater ratio of Pb_{206} to the less amount of Ur-radium.

If there is, as appears (Fig. 2) most consistent, only a small amount of Ur-actinium present, then the rate of disintegration of the Ur-radium is about $1.475(10)^{-10}$ and the formula for age becomes in millions of years: Age $= 15580 \log. (1 + 1.516 \text{ RaG/Urra})$
 $= 1075$ million years.

(2) AGE OF WILBERFORCE URANINITE BY THORIUM LEAD— $\text{ThD} = \text{Pb}_{208}$

According to Aston's results and previous figures there is in the Pb 5.8 per cent of $\text{Pb}_{208} = 0.529 = \text{ThD}$.

¹⁹ T_{Urra} means the half life of that uranium isotope which is the parent of radium.
 T_{Urac} means the half life of that uranium isotope which is the parent of actinium.

TABLE OF COMPARATIVE AGES OF WILBERFORCE URANINITE BY RADIUM AND ACTINIUM FOR VARIOUS ASSUMED PROPORTIONS OF UR-
RADIUM TO UR-ACTINIUM BY SLIDE RULE. (Last figure not accurate. Base of Fig. 2.)

1	2	3	4	5	6	7	8	9	10	11
1.00	1.474	4700	15600	1075	53.52	0.00	∞	0	∞	0
.998	1.477	4691	15570	1075	53.4	0.12	29.5	0.0230	7.94	749
.997	1.478	4680	15562	1075	53.36	0.16	19.7	0.420	5.56	946
.996	1.480	4675	15550	1078	53.31	0.21	14.75	.0469	4.23	1123
.995	1.483	4670	15500	1080	53.2	0.32	11.8	.0585	2.81	1135
.99	1.491	4660	15430	1073	52.9	0.62	5.91	.1170	1.45	1510
.98	1.506	4600	15280	1073	52.4	1.12	2.95	.2345	.803	2000
.97	1.521	4550	15140	1073	51.84	1.68	1.98	.3500	.535	2160
.95	1.555	4450	14810	1072	50.8	2.72	1.18	.5860	.329	2410
.90	1.640	4220	14050	1066	48.1	5.42	.591	1.1700	.165	2590
.89	1.658	4175	13900	1066	47.6	5.92	.536	1.2900	.152	2640

Column 1. Ratio of $\frac{U_{ra}}{U}$.

Column 2. λU_{ra} required to supply 100 atoms of radium to 4 of actinium in equilibrium, λU being $1.535(10)^{-10}$ atoms per year.

Column 3. $T_{Ura} = \text{half life} = \frac{0.692}{\lambda U_{ra}}$ in millions of years.

Column 4. $\frac{2.3}{\lambda U_{ra}} = 3.323 T$.

Column 5. Age in millions of years = $3.323 (T) \log \left(1 + 1.156 \frac{RaG}{U_{ra}} \right)$; $RaG = 7.97$; $1.156 RaG = 9.21$; $3.323T$ is given in Column 4.

Column 6. Ur-radium, per cent of.

Column 7. Ur-actinium, per cent of.

Column 8. $\lambda U_{rac} = \frac{4}{104} \times 1.535(10)^{-10}$ (proportion of ur-actinium) in units of $(10)^{-10}$ atoms per year.

Column 9. $T_{Urac} = \frac{0.692}{\lambda U_{rac}}$ in billions of years.

Column 10. $\frac{0.889}{U_{ur-actinium}}$. Actinium D = 0.77 (Aston).

Column 11. Age by actinium from the formula: age in million of years = $3.323 \times T_{Urac} \times \log \left(1 + 1.153 \frac{\text{Actinium D}}{U_{ur-actinium}} \right)$

Authorities differ on the rate of disintegration and of lead production and half life (T) of thorium.²⁰ Kirsch says it is a quarter of that of U. This would mean a life four times as long. Bulletin 80 (Kovarik) uses a factor 0.36; the International Critical Table 0.38. Thus, Age = 1020 (up to 1620) million years.

It must be remembered, however, that if uranium and thorium are composed of any isotopes of unequal rate of decay the rate will slow up as those more rapidly decaying disappear. So that the rate of production compared to that of uranium of lead by thorium (k) may not be the same now as it has averaged in the past. This will in part account for the discrepancy between Kovarik and Kirsch. If we take the age we found from Ur-radium from the previous section we can find what value of k will fit. To check perfectly with the age just obtained Ur-radium to lead, 1075 ± 8 million years, we should have:

$$\text{Age} = 1075 \pm 8 = 44,000 \log. \left(1 + 1.115 \frac{0.529}{10.37} \right) = 3.323 T_{\text{Th}} (.024 -).$$

Therefore, $T_{\text{Th}} = 13,250(10)^6$, and $\lambda_{\text{Th}} = 0.522(10)^{-10}$. This indicates a $k = 0.36 = 0.522(10)^{-10} / 1.475(10)^{-10}$, just the value used in N.R.C. Bulletin 80.

(3) AGE OF WILBERFORCE URANINITE BY CHANGE FROM UR-ACTINIUM TO ACTINIUM— $D = \text{Pb}_{207}$

From Aston we have $\text{Pb}_{207} = 8.3$ per cent of $9.26 = 0.77$. This is about in the middle of the range of possibilities assigned by Kirsch and Lane (Fig. 1).

The age = $3.323 T_{\text{Urac}} \log. (1 + 1.153 \cdot 0.77 / 1.61r)$ where r is proportional to the half life of the Ur-actinium and is defined as follows: $r = 4 \text{ Urac} / 3 \text{ Ur}_{\text{ra}}$. If there was only 0.16 of Ur-actinium r would be 0.1 and T_{Urac} would be 0.075 of $T_{\text{Ur}_{\text{ra}}}$ and the age would be in millions of years $2.3 / 19.67(10)^{-10} \log. (1 + 0.77 / .161) = 956$ million years. And if we take Ur-actinium as $0.2 = .00375 \text{ U}$

$$\lambda_{\text{Urac}} = \left(1.535(10)^{-10} \times \frac{4}{104} \right) / \left(\frac{0.2}{53.52} \right) = 15.79(10)^{-10}$$

and the age = $2.3 / 15.79(10)^{-10} \log. (1 + 1.153(.077) / 0.2) = 1073$ million years. This checks much more closely with the age by Ur-radium and Thorium than the accuracy of the chemical analyses warrant, and may be taken as giving as accurate a value of the

²⁰ Int. Critical Tables I, p. 362, $1.31(10)^{-10}$ up to 2.37?

rate of disintegration of Ur-actinium as we have. The half life $= 0.69/15.79(10)^{-10} = 4.3(10)^8$ years, which is near that derived by von Grosse from bröggerite.

The table and Fig. 2 show the results of assuming various proportions of Ur-actinium.

(4) AGE OF WILBERFORCE URANINITE BY OXYGEN

When Dr. Kirsch and I²¹ discussed the age of the Wilberforce uraninite, which had been described by Ellsworth and Spence and others, we did not attempt to compute the age by the oxygen method on account of uncertainties Ellsworth mentioned. Yet it seems as though it had a value in giving a maximum age, in freedom from uncertainties as to the atomic weights and relative properties of the different leads.

It is interesting to find that in spite of the large amount of lead J. T. Norton, Jr. finds the uraninite crystal lattice remains that of UO_2 . Therefore, we may naturally ask if the large atoms of oxygen have not retained their places, and the oxygen present, be that originally there.

We have therefore taken the analysis made by H. V. Ellsworth, one by F. Hecht on identically the same material as that used by Baxter and Bliss²² and by R. C. Wells²³ and another by the same analyst of a crystal from the same lot, obtained (by slide rule) the molecular proportions of all the U, Pb, Th, Ce, Y, Fe, and Al oxides, then found the proportions of the atoms of metal and of oxygen, Table 3. We find that the proportion of oxygen to metal is a little more than 2 to 1. But if we assume that the O of the PbO has really already been counted as O of the UO_3 and the summation of the analyses is high, then the ratio becomes as nearly 2 to 1, as different good analysts agree on the amount of U present.

It is conceivable then that from the O of the RO_3 one might infer the amount of UO_2 originally present $= 7.44$ O.

Yet it is probable that a little of the Fe_2O_3 and Al_2O_3 present were originally combined in some silicate like hornblende and some oxygen may well be attributed to external oxidation. In his discussion of the present rate of disintegration of U, Kovarik²⁴ quotes

²¹ *American Acad. of Arts and Sciences*, Vol. 66, pp. 363-372.

²² *Jour. Am. Chem. Soc.*, 62, p. 4848, 1930.

²³ *Am. Acad. Arts and Sciences*, 66, p. 364.

²⁴ National Research Council Bull. 80, pp. 86 to 92. See also p. 208.

TABLE 3.

OXYGEN IN WILBERFORCE URANINITE

	Atom proportions		Hecht & Wells	Atom proportion		Hecht & Reich-Rohrwig	
	H.V.E.						
UO ₂	39.10	.145 U	62.12 ¹	.2226 U	.5930 O	69.10	.660
UO ₃	32.40	.1132				.3480	
U			53.52				
PbO	10.95	.049	10.45	.047 Pb	.047	10.80	.049
ThO ₂	10.60	.0514	10.33	.039 Th	.0397	14.42	.1108
CeO ₃	1.88	.01	2.04	.01 ±	.02 ±	2.60	.03
Y ₂ O ₃	2.14	.02	1.64	.02 ±	.03 ±	1.49	.03
Fe ₂ O ₃	0.43	.005					
Al ₂ O ₃	0.09	.002					
Total metal		.3956		.33 (9)		.3824	
Total O		.8524			.7297		.8798
less for O of PbO		.8034			.6827		.830
for Fe ₂ O ₃ and Al ₂ O ₃		.7924		.32	.65		
Ratio		.3886		2.03	2.03	.217	
SiO ₂	0.19	2.07				0.36	
CaO	1.01					0.85	
MgO	0.08					0.25	
MnO	0.03						
H ₂ O	0.05					0.0	
H ₂ O	0.65					0.0	
Insol.	0.31						
Sp. gr.	100.06					100.60	
	9.062						

¹ The UO₂ and UO₃ are not separated, but in the very same sample R. C. Wells found 53.52 U and von Grosse and Kurbatov 52.71, and Hecht's 62.14 of U₃O₈ gives 52.6. This sample was from a large 700 gram crystal used to obtain lead and uranium for atomic weights, and some fluorite was attached.

figures from 5,000 down and the International Critical Tables gives 4,670. The uncertainty is probably less than 5 per cent but shows that we can not, at present, expect an accuracy of one per cent in our calculations, and slide rule calculations are accurate enough.

The formula for age in millions of years becomes: (U_0 is uranium originally present and all isotopes are included)

$$\text{Age} = 4520 \times 3.323 \log. U_0/U$$

$$= 15,000 \log. U_0/U = 15,000 \log. 7.44 O/U$$

	I	II	III	IV
$UO_2 =$	39.10	45.18	13.55	
$UO_3 =$	$\frac{32.40}{71.50}$	$\frac{24.90}{69.08}$	$\frac{52.04}{65.59}$	61.96
$U_0 =$	$\frac{61.44}{10.06}$	$\frac{60.56}{8.52}$	$\frac{52.26}{10.33}$	$\frac{53.52}{9.44}$
$U_0 =$	74.6	63.5	77.0	70.4
Age =	1268	304	2460	1785 million years

No. III is obviously oxidized and gives too high an age.

The result by No. I of Ellsworth checks fairly with that by Uranium Pb_{206} , the most reliable method (1070 million years). IV by Wells is not so far off.

In No. II one may suspect such troubles in the chemical method as Ellsworth describes. A small difference in the amount of oxygen and uranium found will make very large difference in the age computation. 1.3 per cent more O would make the results of Analysis II agree with I. As to the chemical work, Ellsworth writes (Nov. 30, 1932):

"When I first thought of using this method and Professor S. Beatty and I calculated the results for some of our analyzed uraninites we always found too much UO_3 (or not enough UO_2). This of course can be explained by assuming weathering, etc. Also it may be that the mathematics does not make proper allowance for an *acceleration* of oxidation that may be conceived to take place as time goes on due to U of UO_3 breaking up."

(5) AGE OF WILBERFORCE URANINITE BY HELIUM

W. R. Bennett found²⁵ in three 15-gram portions of the same sample of Wilberforce uraninite on which the atomic weight deter-

²⁵ *Proc. Am. Ac. Arts and Sciences*, **66**, p. 372.

minations were made 15.605, 15.543, and 15.620 cc. of helium. This gives an average amount of 10.39 cc. of helium per gram of ore. The age, owing to the loss by diffusion, is always less in minerals with so much helium. The age Kirsch and Lane gave was, by an earlier approximate formula, $10.39/53.52 + 2.9 \times 9.10(10)^8 = 168$ million years. Bennett estimated 166.8 million years. But the ratios to the bröggerite which von Grosse studied are similar.

$$\begin{array}{ll} \text{The helium ratio for Wilberforce is} & \frac{.185}{.14} = 1.32 \\ \text{The helium ratio for Annerod bröggerite is} & \end{array}$$

$$\begin{array}{ll} \text{The lead ratio for Wilberforce is} & \frac{.165}{1.39} = 1.19 \\ \text{The lead ratio for bröggerite is} & \end{array}$$

Both indicate that the Wilberforce uraninite is older.

(6) AGE OF WILBERFORCE URANINITE BY PROPORTION OF ISOTOPES IN LEAD

If we assume that all uranium in the first place had the same proportion of isotopes and that their rates of disintegration varied, the older the lead the larger must be the proportion of the lead from the more rapidly disintegrating isotope, and as von Grosse points out we might find the age even if we did not have all the analytical figures to use the other methods, simply from the determination of the proportions of isotopes.

(7) AGE OF WILBERFORCE URANINITE BY SPECIFIC GRAVITY

Could we assume that spacing of the atomic network did not change from disintegration, loss of helium would show in the specific gravity which should decrease from 10.89 in a ratio $x270.14 + y238/270.14$ where x is the the proportion of UO_2 and y is the remaining Pb and O. It is true that the younger uraninites have greater specific weights up to that practically demanded by the crystal network. However, analytical methods do not suffice, since it is by no means certain that the network will remain unaltered.

MINERALS FROM TOPAZ MT., UTAH

CHARLES PALACHE, *Harvard University.*

In the spring of 1933 Mr. Edwin Over, Jr. of Colorado Springs made a mineral collecting trip in the interest of the Harvard Mineralogical Museum. The largest part of his time was spent at Topaz Mt. in the Thomas Range, Utah, and he succeeded in obtaining a very fine suite of the well-known topaz of that locality. He also added several minerals to the paragenetic series there as hitherto recorded. These additions are pseudobrookite, beryl, fluorite and calcite.

TOPAZ: The topaz collected is nearly all of the pale wine-color long known from Topaz Mt. The crystals are in part in typical lithophysae in the rhyolite, in part in small gash veins or vein-like cavities more or less completely filled with late calcite. The finest specimen is a doubly terminated crystal of beautiful quality about 3 cm. in length. The walls are lined with minute quartz crystals and the quartz continued to form throughout the period of mineral formation, as crystals of it are included both in topaz and beryl. When calcite is present it is in snow-white masses, coarsely crystallized, massive, and completely filling the cavities. Again it projects from the walls in platy form, the crystals showing the outline of a hexagonal prism of first order and a rough basal plane, evidently modified to a rough surface by etching. The pale purple fluorite is intermingled with it and shows no definite crystals.

BERYL: This mineral, so unfamiliar in such surroundings, has been reported recently from this locality under the name of apatite. A considerable amount of blasting yielded only a small number of specimens. It is in the form of small crystals of rose-red color attached to the cavity wall or to topaz. The crystals are tabular, simple combinations of prism and base, and rarely reach a diameter of 5 mm. and a height of 3 mm. The color is a delicate pink and somewhat variable. Under the microscope the crystals show a zonal structure, the zones having slightly varying optical properties. They enclose tiny quartz crystals.

I am indebted to Mr. Harry Berman for the following optical data. The crushed crystals show a variation in refractive index from $\omega = 1.580 \pm$ to $\omega = 1.570 \pm$. This variation is due apparently to zoning. The average values are $\omega = 1.576$, $\epsilon = 1.570$. These values indicate a beryl low in alkalis. The specific gravity $2.67 \pm .01$ likewise indicates a low alkali content. It is hoped later to have a chemical analysis made of this rose beryl.

THE OXIDE MINERALS: The association of oxides in the rhyolite cavities is not without interest. They include hematite, Fe_2O_3 ,

pseudobrookite, $\text{Fe}_2\text{O}_3 \cdot \text{TiO}_2$, and bixbyite, $(\text{Fe}, \text{Mn})_2\text{O}_3$. Hematite is in the form of tiny plates, attached to the cavity walls or to other earlier minerals by an edge and showing, besides the basal pinacoid, only the forms $r(10\bar{1}1)$, $e(01\bar{1}2)$, and $n(22\bar{4}3)$ as narrow facets. Bixbyite is included in Mr. Over's collection, but the new material adds nothing to the original description of the mineral by Penfield and Foote (*Am. J. Sc.*, **4**, 105, 1897). Pseudobrookite is new to the locality and is present in occasional cavities in tufts of minute needles, associated with hematite, with topaz and particularly with beryl. The minute, millimeter-long needles are of brilliant metallic lustre and proved measureable despite their minimal faces. The crystals are too few to yield material for chemical analysis, but the crystal form is conclusive as to their nature. They show the forms and habit of the figure. The following table contains the average measurements and range of angles for each form present and observed on five crystals. The elements at the head of the table were calculated from all the better angles and agree well with the best values previously obtained on crystals of this mineral. In another place the position and elements of pseudobrookite from this and other localities are discussed and a new angle table is given. Pseudobrookite has hitherto been observed from but one American locality, Crater Lake, Oregon, where it occurs with apatite and hypersthene in a cavity in basalt. It was described by the author in a note in Diller and Patton's monograph on that region (*U.S.G.S. Prof. Paper 3*, 147, 1907).¹

PSEUDOBROOKITE. MEASURED ANGLES AND LIMITS.

				$a=0.9791$	$p_0=0.3837$				
				$c=0.3757$	$q_0=0.3757$				
		ϕ	ρ	Limits ϕ	Limits ρ	Faces	Cryst.	Qual.	
b	0^∞	010	$0^\circ 23'$	$90^\circ 00'$	$0^\circ 02' - 0^\circ 58'$	6	4	good	
a	$\infty 0$	100	88 51	90 00	88 05 - 90 03	6	4	fair	
n	$\frac{1}{2}^\infty$	120	26 09	90 00		1	1	good	
h	$\frac{3}{4}^\infty$	340	36 51	90 00	36 28 - 37 15	2	1	poor	
m	∞	110	45 23	90 00	45 23 - 46 06	6	4	fair	
μ	2^∞	210	63 48	90 00	63 32 - 63 57	4	2	good	
e	10	101	90 07	21 00	89 17 - 90 45	20°54' - 21°05'	9	5	excell.
q	1	111	45 37	28 11	45 17 - 46 12	27 54 - 28 15	11	5	good
s	12	121	26 53	40 23	26 14 - 27 52	39 55 - 40 46	4	2	poor
p	13	131	18 35	49 57	17 09 - 19 14	49 51 - 50 10	14	4	poor

¹ Since writing this paper my attention has been called to the fact pink beryl was found in this locality by Mr. Bixby as long ago as 1905 and that an approximate analysis was made by W. F. Hillebrand showing that it was a beryl with an appreciable amount of manganese. The notice appeared in *Am. J. Sc.*, **19**, 330, 1905.

PSEUDOBROOKITE

CHARLES PELACHE, *Harvard University.*

The best position and the elements of the uncommon mineral pseudobrookite have been the subject of numerous studies and there is little uniformity in their treatment by various authors. Doubtless the small size and poor average quality of the crystals available have combined to lead to this result. A recent crystallographic study of pseudobrookite from Utah by the writer yielded results that seem at least as good as any previously published and led him to review the data on the subject which are here collected in brief résumé and in tabular form.

Pseudobrookite was first described and named by A. Koch (1) whose crystals came from cavities in the andesite of Aranyer Berg, Transylvania. Groth (2) reviewed this article, showing that Koch's calculations were erroneous. He made a new calculation from the original data, interchanging the b and c axes in order to bring out a somewhat remote isomorphism with brookite.

Schmidt (3) remeasured Koch's crystals and others from the same locality. He retained Koch's position and calculated new axes from his two reliable angles. Vom Rath (4) gave values for the same two angles and also rejected Groth's brookite position. Lewis (5) measured a single minute crystal from Jumilla, Spain. He gave two angles as dependable, used Koch's position but chose a different unit form. Oebbecke (6) described the pseudobrookite of Mt. Dore, France. He adopted the position of Groth, determined elements on the basis of the same two fundamental angles, and described several pyramid forms for the first time.

Cedarström (7) studied the large rough crystals from the wagnerite vein of Havredal, Norway. He first determined the true chemical nature of pseudobrookite, having for the first time sufficient material for adequate analysis. Latterman (8) isolated microscopic crystals from the nephelinite of the Katzenbuckel, Baden, but added no crystallographic data. Krenner (9) described a crystal from Vesuvius, determining elements based on two measured angles. Groth (10) abandoned the brookite analogy, readopting Koch's position and using the elements of Schmidt. Goldschmidt (11) interchanged the a and c axes of Groth's earlier position and employed mean values of the elements. Dana (12) adopted Groth's position and Schmidt's axes, recalculated to that position. He was

followed by Goldschmidt (13) in the Winkeltabellen, who, however, used as elements the mean of several determinations.

Traube (14) restudied the pseudobrookite of Aranyer Berg, having collected new and more abundant material. His crystallographic results reduce, however, to two angles, means of widely varying observations, measured on a single crystal. He added one new and very dubious pyramid.

Bruno Doss (15), after giving a full summary of previous work on the mineral, presented a study of artificial crystals of pseudobrookite formed by sublimation in a furnace. He gave elements in the position of Koch and a simplified chemical formula. He also showed a possible isomorphic relation to andalusite, no more probable than was Groth's to brookite.

Lacroix (16) added nothing to Oebbecke's description of the Mt. Dore crystals, but used the Koch position for his figure. Palache (17) described pseudobrookite from Crater Lake, Oregon, but his measurements served only for identification of forms.

Mark and Rosbaud (18) and Pauling (19) made *x*-ray measurements on crystals of pseudobrookite from Aranyer Berg. They established unit cells of very similar dimensions, both requiring a *c* axis but one-third the length of that assumed by the morphological investigators. Pauling also accepted as established by his work the simplified chemical formula, Fe_2TiO_5 .

Palache (20) measured several crystals of pseudobrookite from Topaz Mountain, Utah. The crystals were needles, elongated in the direction taken as the vertical axis. Before the identity of the mineral was known he had taken as unit form a pyramid which gave elements practically identical with those demanded by the dimensions of the unit cell of Pauling. He, therefore, feels no hesitation in adopting those elements as the most appropriate for the mineral. In the following Table 1 will be found the data given by the authors whose work has been cited above. Consideration of this table makes it clear that the angles of pseudobrookite from different localities show considerable variation. It was, therefore, thought best to take the mean of the elements which seemed based on the best data. For this purpose those of Schmidt, Lewis, Oebbecke, Krenner, Traube, Doss and Palache were selected. The average of these values gives as the most reliable elements of pseudobrookite $a=0.9777$, $c=0.3727$. From these elements there has been calculated a new Angle—table 2.

1. TABLE OF OBSERVATIONS ON CRYSTALS OF PSEUDOBRUKITE

Author	Locality	Fundamental Angles	Elements of author	Elements recalculated to new position	Forms (letters of present author)
Koch (1) } Groth (2) }	Aranyer Berg	$a:m$ 44°06' $a:l$ 41 19	$a = .8790$ $c = .9071$	$a = .9690$ $c = .3675$	b, a, m, μ, e, l, y
Schmidt (3)	Aranyer Berg	$a:\mu$ 26 23 $a:l$ 41 16½	$a = .9922$ $c = 1.1304$	$a = .9922$ $c = .3768$	b, a, n, m, μ, e, l, y
Vom Rath (4)	Aranyer Berg	$a:\mu$ 25 50 $a:l$ 41 15	$\left(\begin{array}{l} a = .9683 \\ c = 1.1403 \end{array} \right)$	$a = .9683$ $c = .3801$	
Lewis (5)	Jumilla	$a:\mu$ 25 46 $a:e$ 69 02	$a = .9676$ $c = .5564$	$a = .9676$ $c = .3709$	a, μ, e
Oebbecke (6)	Mt. Dore	$a:\mu$ 26 03½ $a:e$ 69 04	$a = .8714$ } mean $c = .8910$ }	$a = .9780$ $c = .3741$	b, a, μ, e, l, g, s, p
Krenner (9)	Vesuvius	$a:\mu$ 25 50 $a:e$ 69 20	$a = .9683$ $c = 1.0957$	$a = .9683$ $c = .3652$	a, μ, e
Traube (14)	Aranyer Berg	$a:\mu$ 26 08 $a:l$ 41 02½	$a = .9812$ $c = 1.1268$	$a = .9812$ $c = .3756$	b, a, m, μ, e, l, o (772) ?
Doss (15)	Artificial	$a:\mu$ 26 02½ $a:e$ 69 11	$a = .9773$ $c = 1.1147$	$a = .9773$ $c = .3716$	b, a, μ, e, q
Mark & Rosbaud (18)	Aranyer Berg	Unit Cell	$a = .998$ $c = .375$	$a = .998$ $c = .375$	
Pauling (19)	Aranyer Berg	Unit Cell	$a = .986$ $c = .375$	$a = .986$ $c = .375$	
Palache (20)	Topaz Mt.	$a:\mu$ 26 09 $a:e$ 69 00		$a = .9791$ $c = .3757$	$b, a, n, h, m, \mu, e, q, s, p$
Mean of elements of Schmidt, Lewis, Oebbecke, Krenner, Traube, Doss & Palache		Calculated $a:\mu$ 26 03 $a:l$ 41 10 $a:e$ 69 08		$a = .9777$ $c = .3727$	

TABLE 2
PSEUDOBROOKITE

No.	Miller	ϕ	ρ
1	010	0°00'	90°00'
2	100	90 00	90 00
3	120	27 05	90 00
4	340	37 29½	90 00
5	110	45 39	90 00
6	210	63 57	90 00
7	031	0 00	48 11½
8	101	90 00	20 52
9	301	90 00	48 50
10	111	45 39	28 04
11	121	27 05	39 56
12	131	18 49½	49 45



Pseudobrookite

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THE BLOW-ME-DOWN INTRUSIVE COMPLEX, BAY OF ISLANDS, NEWFOUNDLAND*

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Reconnaissance in the western "serpentine belt" of Newfoundland in the summer of 1932 by a Princeton party under the supervision of the senior author has disclosed a series of pseudostratified intrusive rocks, the petrogenetic significance of which merits a note at this time.

REGIONAL SETTING

Blow-me-down mountain is located on the south shore of Bay of Islands, on the west coast of the island of Newfoundland. The nearest town is Corner Brook, situated at the head of the bay, twenty miles southeast.

Geologically, the Blow-me-down area forms part of the western "serpentine belt" of the island which extends for a distance of sixty-five miles parallel and adjacent to the west coast. The Bay of Islands section is at the middle of this belt and is approximately six miles wide, east to west.

The west coast of Newfoundland is for the most part a narrow, flat lowland of folded Paleozoic formations. In strong contrast to this topographically is the "serpentine belt," of late Ordovician or Devonian ultrabasic and basic intrusives, which rises out of the lowland and attains a mean altitude of 2,000 feet. These intrusives are characterized by the same peneplained upland surface which is found farther east on the pre-Cambrian rocks of the northern peninsula of Newfoundland.

In the immediate vicinity of Blow-me-down mountain the rocks surrounding the "serpentines" are steeply folded green (glauconitic) and red sandstones, black and gray slates, and red and gray argillites, presumably of Ordovician age.¹ Overlying these with probable unconformity are andesitic lavas, commonly with well-developed pillow structure, and containing occasional pyroclastic beds. The south shore of Bay of Islands near Blow-me-down mountain is not composed of intrusives, as represented on the official geological map of Newfoundland, but is underlain by a narrow fringe of these sediments and lavas, probably down-faulted.

* Princeton University Contribution to the geology of Newfoundland, No. 10.

¹ Schuchert, C., and Dunbar, C. O., Stratigraphy and Diastrophism of Western Newfoundland: *Bull. G.S.A.*, Vol. 32, no. 1, pp. 38-39, 1921.

THE BLOW-ME-DOWN COMPLEX

The form of the intrusive complex, as at present understood, is that of a lopolith. Although actual contacts were not observed, the dip of well-marked pseudostratification near the eastern edge of the mass is concordant with the dip of the country rock, about 40° westward. (See Fig. 1.) What are believed to be the bottom horizons of the complex appear one mile southwest of York Harbor Copper mine from under a partial cover of lavas; the order of the bands, however, is the reverse of that shown from right to left on the accompanying map, thus suggesting that the intrusion is basin-shaped. The total thickness of the complex appears to be of the order of magnitude of 1.5 miles.

Several traverses across the eastern portion of the complex, inward and upward from the base, reveal the following sequence and approximate actual thicknesses: (1) Serpentinized harzburgite (pyroxene-olivine rock), 3,000 feet, including 1,000 feet of dunite



FIG. 1. The eastern portion of the Blow-me-down complex.

at 1,300 feet above the base. In the dunite appear narrow lenticular segregations of pegmatitic pyroxenite, and also schlieren of chromite; (2) Gabbro, 500 feet, evidently intrusive into the harzburgite in the vicinity of Blow-me-down Falls; (3) Troctolite (olivine-plagioclase rock), 1,000 feet; (4) Diorite, 2,300 feet; (5) Gabbro, undetermined thickness. Minor dikes of diorite are present locally in the lower gabbro band, and of granite in the troctolite zone.

The chromite occurrences in the complex were prospected some years ago by trenches and pits. No ore remains in place at the localities shown in Fig. 1, but three other deposits are known in the western "serpentines" of Newfoundland, and at least one of these (on the north shore of Bay of Islands) occupies a similar position in this northward extension of the Blow-me-down complex.

The copper deposit of the abandoned York Harbor mine occurs as replacements in chlorite schist zones in pillow lava, adjacent to diorite dikes. The ore minerals are pyrite, pyrrhotite, sphalerite, and chalcopyrite. There is a strong possibility that this mineralization is related genetically to the diorite of the Blow-me-down complex. In general, a noteworthy resemblance exists between this magmatic sequence and associated mineralization and that of the old copper districts of Notre Dame Bay, on the northeast coast of Newfoundland.²

The Blow-me-down complex in comparison with better known complexes such as the Bushveld, Sierra Leone, Duluth, and Stillwater (Montana) presents interesting analogies and dissimilarities. It is hoped that more extensive and detailed work on the Newfoundland belt of which this complex forms a part will solve some of the problems presented and throw further light on the differentiation of basic intrusives.³

ACKNOWLEDGMENTS

The authors are indebted to Professors A. F. Buddington and Edward Sampson of the Department of Geology, Princeton University, for their interest and advice; and also to Dr. H. H. Hess whose assistance was particularly valuable because of his extensive investigations of the serpentine rocks of the Appalachians.

² Geology and Ore Deposits of Betts Cove-Tilt Cove Area, Notre Dame Bay, Newfoundland: *Bull.* 228, *Can. Inst. of Min. and Met.*, p. 492, April, 1931.

³ Aided by the F. W. Roebeling, III—J. L. Kemmerer, Jr. Aerial Photographic Survey, a detailed study of this region was begun in 1933 by Mr. J. R. Cooper of Princeton University. As a result of this work, the interpretation of details of sequence and structure of the rocks comprising the complex has been modified but the general conclusions remain unaltered.

AN OBJECTIVE WITH A VARIABLE DIAPHRAGM*

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The common method of measuring optic angles from interference figures is that employing the Amici-Bertrand lens or one of its many modifications. The principle involved in the use of the Amici-Bertrand lens is to produce a diminished image of the interference figure which is subsequently magnified by the ocular. The resulting interference figure loses some of its distinctness and sharpness of outline because of this procedure. The diminished image of the interference figure which is produced by the Amici-Bertrand lens falls on the cross-hairs of the ocular. In most microscopes this reduction in size is of the order of one half to one-third. The ocular then magnifies the image according to the power of the ocular giving a resultant interference figure which is from two to five times the size of the interference figure that forms in the rear focal plane of the objective. In order to measure the optic angle a scale is substituted for the cross-hairs of the ocular. This scale is likewise magnified by the ocular in exactly the same ratio as the image of the interference figure and appears superimposed upon that image as seen by the observer. This method is commonly referred to as the Mallard¹ method and the constant of the calibration curve as the Mallard constant.

The chief objection to this method is that the calibration curve is dependent upon so many variable factors. The calibration must be made for a given objective and one particular microscope with a definite tube extension and with an ocular equipped with a scale instead of cross-hairs. If any one of these several factors is varied the calibration curve is in error. The factor that introduces the greatest difficulty is the tube extension. A well defined image of the entire interference figure is difficult to obtain because the figure lies upon a curved surface² and all parts of the figure cannot be in focus at the same time. Even if the microscope is calibrated for one definite tube extension, because all portions of the interference figure are not equally in focus, the image is more indistinct than when observed directly with the ocular removed.

* This investigation was made possible by a grant from the Graduate School of the University of Michigan and through the generous cooperation of the Spencer Lens Company.

¹ Mallard, E., *Bull. Soc. Min. Fr.*, **5**, 77-87, 1882.

² Wright, F. E., *The Methods of Petrographic-Microscopic Research*, 1911, p. 77.

The new objective endeavors to measure the interference figure where it is formed, namely, in the rear focal plane of the objective, by using a variable diaphragm placed at this point. This diaphragm is superimposed directly upon the interference figure itself. For all routine work the calibration of the diaphragm is dependent only upon the objective, and the objective may be transferred from one microscope to another using the same calibration curve. Measurements may be made by direct observation of the interference figure with the ocular removed, or by any of the various methods using the Amici-Bertrand lens. For very accurate measurements the calibration should be made upon the individual microscope to which the objective is attached. In the direct observation of the interference figure the analyzing nicol and the correction lenses accompanying it produce a parallax which introduces a small error. However, the same type of error, though somewhat larger, is produced by the Amici-Bertrand lens system and the ocular when using that method of observation.



FIG. 1



FIG. 2

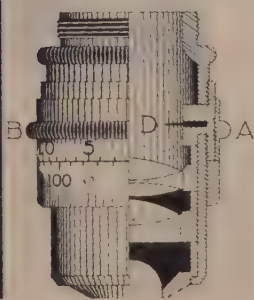


FIG. 3

FIG. 1. Ordinary 4 mm. objective with a variable diaphragm. Figs. 2 and 3. New type of objective with variable diaphragm.

These errors are of the same order of magnitude as those introduced by the indefiniteness of the exact position of the optic axes as determined by the centers of the isogyres. When the isogyres are broad the personal equation in determining the absolute center of the bar is quite large. Wright³ has recommended the use of the Abbe apertometer in calibrating a microscope for the determination of the optic angle by any method. The writer has found

³ *Ibid.*, pp. 148-9.

that it is more satisfactory to use measured sections which duplicate to a considerable extent the same conditions met with in actual practice. A comparison of the variation in the personal equation using the apertometer and measured sections gave consistently higher values for the "apertometer curve" readings. It has also been found, with both methods, that the calibration curve determined by one individual will show a consistent positive or a consistent negative variation when used by another individual upon the same sections.

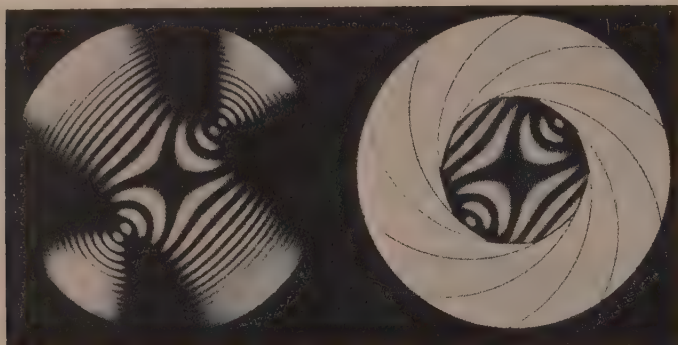


FIG. 4a

FIG. 4b

The diaphragm is calibrated to give the angular distance of any point in the interference figure from the center of the field. Its operation may be best illustrated by using a section of a crystal cut perpendicular to the acute bisectrix with the optic axes visible in the field as in Fig. 4a. If the diaphragm is slowly closed by rotating the knurled collar AB, Figs. 1, 2, and 3, the field of vision shrinks as in Fig. 4b until the optic axes appear exactly at the edge of the field. The scale will then give a reading which will represent E , one half the apparent optic angle. If the bisectrix is not perpendicular to the upper surface of the crystal, each optic axis may be measured separately, provided the optic plane passes through the center of the field. Then the sum of the two values measured may be taken to represent $2E$ without introducing any serious error. The true value of $2V$ may be found from $v' + v''$ for when $\sin v' = \sin D'/\beta$ and $\sin v'' = \sin D''/\beta$, where D' and D'' represent the angular distances of each optic axis from the center of the field, each axis being measured separately.

If one wishes to use a vernier with the scale, the scale on the objective cannot be graduated to read directly in degrees because the distance of the optic axis from the center of the field is not a straight line function of the angle made by the optic axis with the axis of the microscope but approximates the sine of the angle. If the proper size of a standard diaphragm is used, and if the collar operating that diaphragm is calibrated so as to read the angular rotation of the collar in units of two degrees, the scale will read approximately the sine of one-half the apparent optic angle. Thus in the example illustrated, in Fig. 4b, the scale will give a numerical reading equal to the sine of one-half the apparent optic angle of the section. Another way of expressing the same fact is that the scale reads the numerical aperture of the objective for any position of the diaphragm.⁴

A variable diaphragm of this type can be placed in any standard objective at a very reasonable cost. It has uses other than the measurement of interference figures. For instance it lies in a plane conjugate with the plane of the condenser diaphragm so that for many purposes it will serve in the same capacity as the condenser diaphragm. High aperture objectives when used for viewing an object upon the stage of the microscope always show a distinct curvature of the field which prevents all parts of the field of vision from being in focus at the same time. By reducing the aperture of the objective with a variable diaphragm we can flatten the field of vision. Also by the same procedure we can increase the depth of focus of the microscope.

Fig. 1 is an illustration of an ordinary 4 mm. objective which was equipped with a variable diaphragm by the Spencer Lens Co. Figs. 2 and 3 represent an entirely new type of objective constructed by the same company and designed to give an interference figure with four times the area of that produced by the standard 4 mm. objective. This was made possible by constructing an 8 mm. objective with a numerical aperture of 0.85. The increased focal length allows a larger interference figure to be produced and by keeping the high aperture we retain the desirable characteristics of figures produced by the 4 mm. objective. It is especially well adapted for use with substances of high double refraction such as organic compounds. The average organic compound has a double

⁴ Wright, F. E., *Ibid.*, p. 37.

refraction comparable with that of calcite and gives an interference figure with a large number of lemniscate rings. For fine grained material of low double refraction the increased area of the interference figure reduces the light intensity and makes the figure somewhat more indistinct. It should also be pointed out that for direct vision of the object the magnification is reduced to one-half that of the 4 mm. objective and the field of vision has twice the diameter.

The use of the new objective for teaching purposes has been found to offer distinct advantages because the larger interference figure greatly aids the untrained eye of the beginner. In developing the theory of certain fundamental characteristics of the interference figure the diaphragm may be used to point out the features under discussion. It is hoped also that the advantages of a variable diaphragm in the objective when using the microscope for direct observation may increase the usefulness of the polarizing microscope.

NOTES AND NEWS

SODALITE FROM BOLIVIA

WOLFGANG BRENDLER, *Hamburg, Germany.*

Beads and carved images of sodalite have been found in ancient Indian ruins at numerous places on the Bolivian and Peruvian highlands of the Andes. A. Stuebel was the first to collect relics of sodalite in the ruins of Tihuanacu (Tiahuanaco), a settlement of the Aymara Indians near La Paz, Bolivia. These were examined and described by H. Fischer,¹ E. Bamberger and H. Feussner.² Prodgers who visited Bolivia in 1905-1906 makes the statement that the "Cura of Palca" told him that the early Jesuits had found "lapis lazuli" in the northern part of the Cerrania of Palca, and that the archbishops adorned themselves with chains of this material.

During his journeys through the Andes Fr. Ahlfeld of Marburg saw specimens of blue sodalite in several Bolivian collections labeled from "Ayopaya, Cochabamba" or "Cerro Sapo." In 1928

¹ *Zeit. f. Kryst.*, 4, 370, 1880.

² *Zeit. f. Kryst.*, 5, 580, 1881.

he prospected in this general vicinity and rediscovered the old sodalite mines.³

The locality is in the northern part of "Cerrania of Palca," which belongs to the east Cordillera of Cochabamba. The path to the sodalite mines reaches the locality, situated on the east side of the Cerro Sapo, after crossing the ridge of mountains at an elevation of 13,000 feet. The sodalite occurs in a large dike that accompanies a small stock of nephelite syenite which cuts through lower Devonian sandstones. The sodalite occurs in large, irregular shaped veins associated with greenish white ankerite and yellowish barite.

At various places along the dike Fr. Ahlfeld observed large caves and tunnels. The largest cave measured nearly 300 ft. in length and 16 feet in height. It seems quite likely that the larger openings represent the primitive operations of the Indians who appreciated the beauty of the fine blue mineral. Later the Jesuits continued the work of the Indians at several of the most promising localities. Since no other occurrences for sodalite in the Andes are known, it is highly probable that all the material now found in the ruins of Indian settlements was derived from this one locality. Another proof for this belief is the uniform microscopical structure of all the sodalite carvings found in the various ruins.

The Cerro Sapo sodalite is always coarsely crystalline and shows good dodecahedral cleavage. The color of the fresh material is a fine dark ultramarine blue. Single crystals, found in veins, are often unusually large, measuring at times up to $3\frac{1}{2} \times 2\frac{1}{2} \times 2\frac{1}{2}$ inches. Numerous inclusions are scattered throughout the sodalite mass. Especially on the surfaces of the larger crystals are found minute galena cubes (up to 6 mm. in diameter), small sphenoidal crystals of chalcopyrite, cubes of pyrite and, sparingly, small tetrahedrons of sphalerite. On specimens taken from the exposed parts of the dike the ankerite, siderite and pyrite are altered to limonite, often forming pseudomorphs, while the sodalite is weathered to a mixture of zeolitic minerals.

Thin sections of the fresh sodalite show microscopic inclusions consisting mainly of very thin plates of a red translucent mineral. Plates of a greater thickness are opaque and reflect the light with a greenish color. These inclusions are probably hematite which also

³ Fr. Ahlfeld and R. N. Wegner, Ueber die Herkunft der im Bereich altperuanischer Kulturen gefundenen Schmuckstuecke aus Sodalith: *Zeit. f. Ethnologie*, 63, 288-296, 1931.

explains the relatively high content of iron oxide in this sodalite. Also, sparingly, needles of a greenish translucent mineral were observed, representing perhaps an alkaline amphibole.

The specific gravity of selected pure material was found to be 2.295 ± 0.001 at 14.5°C ., which is in close agreement with the value of 2.290 found by L. Pauling⁴ using *x*-ray methods.

The refractive indices were determined on a polished plate of fresh material using an Abbe refractometer and monochromatic light. The average values obtained were as follows: $N_{\text{Li}} = 1.4806$; $N_{\text{Na}} = 1.4837$; $N_{\text{Ti}} = 1.4868$. These are in good accord with the values found by H. Feussner on sodalite from Mount Vesuvius: $N_{\text{Li}} = 1.4808$; $N_{\text{Na}} = 1.4839$; $N_{\text{Ti}} = 1.4869$.

The following three chemical analyses were made by the author on carefully selected material from Cerro Sapo. The analysis of E. Bamberger, on material collected by A. Stuebel from the ruins of Tihuanacu (Tiahuanaco) is given in the fourth column.

ANALYSES OF SODALITE FROM BOLIVIA

	I	II	III	IV
Na ₂ O	24.54%	24.53%	24.51%	22.93%
K ₂ O	1.01	1.13	1.16	0.74
CaO	—	—	—	0.46
Fe ₂ O ₃	1.06	0.70	0.81	0.85
Al ₂ O ₃	31.08	31.17	31.14	30.96
SiO ₂	36.63	36.72	36.70	37.96
Cl	7.20	7.22	7.21	5.34
H ₂ O (110°C.)	0.31	0.23	0.19	1.10
	101.83	101.70	101.72	100.34
-O=Cl ₂	1.63	1.63	1.63	1.21
	100.20	100.07	100.09	99.13

It is not possible to determine the water content of sodalite by heating to a red heat as it was shown by E. Bamberger that sodium chloride is driven off in noticeable amounts when powdered sodalite is strongly heated. For the same reason alkali determinations according to the Lawrence Smith method should be avoided.

No traces of FeO, S, or TiO₂ were found in the Cerro Sapo sodalite. The small content of water and the high percentages of sodium, potassium and chlorine indicate the purity of the analyzed

⁴ *Zeit. f. Kryst.*, **74**, 213, 1930.

material. On the contrary, analysis IV by E. Bamberger, shows that the amounts of alkalis and chlorine decrease when sodalite weathers while the water content increases.

The following ratio of Cl:Si in the analyses I–III is in good accord with the formula $3\text{NaAlSiO}_4 \cdot \text{NaCl}$:

I	II	III	$3\text{NaAlSiO}_4 \cdot \text{NaCl}$
1:3.00	1:3.00	1:3.00	1:3.00

As many sodalites contain very little or no iron oxide it is probable that the iron oxide found in the pure Bolivian material is due to microscopic impurities, in this case most likely hematite. If we omit the iron oxide and recalculate the analyses we obtain the following compositions which are in very good agreement with the given formula which is also the one accepted by L. Pauling as a result of his *x*-ray investigations.

	I	II	III	$3\text{NaAlSiO}_4 \cdot \text{NaCl}$
Na_2O	25.59	25.59	25.60	25.59
Al_2O_3	31.56	31.56	31.55	31.56
SiO_2	37.19	37.18	37.19	37.18
Cl	7.31	7.32	7.31	7.32
	101.65	101.65	101.65	101.65

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, September 7, 1933.

President Trudell presided at a stated meeting, 45 members and 15 visitors being present. Mr. Clifton Mimms was elected a member, and Messrs. John H. Turri and Henry Moor, junior members.

Nineteen reports were made of summer excursions, with exhibits of specimens: Mr. Yost (Franklin, N. J.); Mr. MacNelly (Texas, Pa.); Mr. Moyd (Bridgeport, Pa.,—clear quartz crystals); Mr. Knabe (Wood's Chrome Mine, Line Pit, and Huntingdon Valley, Pa.); Mr. Dornblum (Wood's Chrome Mine, Pa. and Franklin, N. J.); Mr. Vanartsdalen (Holland, Pa.); Messrs. Arndt and Frankenfield (Scotch Plains, N. J.,—calcite, heulandite, and prehnite); Dr. Gillson (Birmingham, Alabama,—barite and fluorite in limestone; Pensacola, Florida,—ilmenite sands); Dr. Cajori (Devil's Head, Tarryall, and Stone Mountain, Colorado); Mr. Gordon (Vesuvius, Italy); Mr. Toothaker (Moore Station, N. J., and New Galena, Pa.); Mr. Knorr (Bridgeport, Pa.); Mr. Cienkowski (western United States); Mr. Trudell (Mexico City, Vera Cruz and Pueblo). Mr. Toothaker described some mineral exhibits at the Century of Progress in Chicago.

Academy of Natural Sciences of Philadelphia, October 5, 1933

President Trudell presided at a stated meeting, with 47 members and 46 visitors present.

Mr. Toothaker announced a Hobby Show to be conducted by the Philadelphia Commercial Museum during Thanksgiving week, for young people under 18 years of age.

The following officers were elected for the coming year:

President: Dr. Joseph L. Gillson

Vice-president: Mr. Harold Arndt

Secretary: Mr. Wylie Flack

Treasurer: Mr. Morrell G. Biernbaum

Councillor: Mr. Charles R. Toothaker

"Gems from the Mineralogist's Viewpoint" was discussed by Mr. Morrell G. Biernbaum and Mr. Charles R. Toothaker, who showed many lantern slides depicting methods of mining and cutting gems in Africa, India and South America.

Academy of Natural Sciences of Philadelphia, November 2, 1933.

A stated meeting was held on the above date with Dr. Joseph L. Gillson in the chair, and 51 members and 42 visitors present. Upon favorable recommendation of the executive council the following were elected members: Messrs. Ralph Hoffa and Rees H. Beresford.

Mr. James G. Manchester addressed the society on "Some Interesting Minerals" illustrated by means of colored lantern slides of outstanding specimens.

Messrs. Frankenfield and Gordon exhibited a series of minerals including micro-lite, manganotantalite, columbite, beryl, topaz, and amazonstone, secured near Amelia Courthouse, Virginia. Mr. Morgan exhibited apophyllite from Moore Station, and polished natrolite from Perkiomenville. Dr. Gillson described a trip with Mr. Knabe to Brinton's Bridge, finding chondrodite; and another trip with Mr. Frorer to Wood's Chrome mine which yielded zaraitite, brucite, magnesite, chromite, and picrolite. Mr. Biernbaum stated that quartz crystals were plentiful at the Herkimer localities.

W. H. FLACK, *Secretary*

NEWARK MINERALOGICAL SOCIETY

The Newark Mineralogical Society held its 138th regular meeting in the library of the Newark Technical School on Sunday afternoon, October 1, 1933, with the president, Louis Reamer, presiding. There was a good attendance of members and guests.

The program for the afternoon consisted of a symposium on "Summer Collecting." Vice-president, Ernest A. Maynard, spoke at length on the minerals he had collected during the past summer in Nova Scotia. His talk was illustrated with maps, photographs and specimens. Talks were also given by Herbert B. Baldwin; Paul Walther; Leonard A. Morgan; John A. Grenzig; Aubrey J. Slater; President Reamer and other members. Many specimens were on exhibition from Anthony's Nose; Sayreville, South River, Bedford, North Carolina, and Herkimer County, New York.

The 139th regular monthly meeting of the society was held on November 5th in the Newark Technical School.

The President, Louis Reamer, presided. At the close of the business session of the 139th meeting, the 18th annual meeting was started with the reading of the annual reports of the Secretary, Herbert L. Thowless, and of the Treasurer, Herman M. Lehman.

The following officers were unanimously re-elected to serve until the November meeting 1934:

President: Louis Reamer, Orange, N. J.

Vice-President: Ernest A. Maynard, Jamaica, Long Island.

Secretary: Herbert L. Thowless, Newark, N. J.

Treasurer: Herman M. Lehman, New Haven, Conn.

The program for the meeting consisted of a "Symposium on Metals." The speakers included William H. Broadwell; John A. Grenzig; Paul Walther; Ernest A. Maynard; John Reiner and the President.

The 140th meeting was held on December 3, 1933. The program consisted of a discussion on the "Preparation and Examination of Microscopic Mounts."

HERBERT L. THOWLESS, *Secretary*

BOOK REVIEWS

ELEMENTS OF OPTICAL MINERALOGY, AN INTRODUCTION TO MICROSCOPIC PETROGRAPHY, Part II. DESCRIPTION OF MINERALS WITH SPECIAL REFERENCE TO THEIR OPTIC AND MICROSCOPIC CHARACTERS. Third Edition. ALEXANDER N. WINCHELL. Pp. XVIII, 459, fig. 362. John Wiley & Sons, Inc., New York, 1933. Price \$6.00 net.

This third edition of Winchell's well-known book has been extensively revised. The frequent new editions are necessary as the science of optical mineralogy is progressing rapidly. The new edition has much new data, and a laudable attempt has been made throughout to enable the user to determine as far as possible the exact chemical composition of a mineral from its optical properties. The descriptions and the graphs for the amphibole, chlorite, tourmaline, scapolite, and zeolite groups have been materially revised.

The most important contribution of the book is the new classification of the silicates into seven groups based on their atomic structure as determined by *x*-ray studies. It is an important forward step and should show more clearly than any previous classification the fundamental relationships of minerals and mineral groups. This new point of view should lead to many advances in the science of mineral genesis and in other directions. A large number of minerals are grouped as silicates not yet classified by *x*-ray studies. A part of these might have been placed with reasonable assurance in their proper group from our present knowledge of the mineral.

Every working petrographer and mineralogist should have a copy of this standard book on optical mineralogy on his work desk.

ESPER S. LARSEN

ON THE MINERALOGY OF SEDIMENTARY ROCKS. A series of essays and a bibliography. P. G. H. BOSWELL. IX+393 pages. Thomas Murby & Company, London. Price 21 shillings.

This book brings up to date, and includes, the progressive reviews on sedimentary petrology compiled by the author for the years 1923, 1924, 1925, and 1927. A section of 125 pages discusses significant papers and points out present trends in this line of work. A second section of the book contains abstracts of 1025 papers on sedimentary petrology and five sets of indexes to the abstracts. These indexes are arranged in the following groups: General, Stratigraphical Horizons, Localities, Minerals, Figured Minerals, and Technique. The publisher is prepared to furnish the abstracts on sheets printed on one side of the paper for those who wish to build up a card index system of abstracts.

The text proper consists of a critical discussion and review of papers considered outstanding in this field. No attempt is made to generalize but the significance of the work accomplished and progress made is pointed out. The questions that are at least partly answered in the discussions of the various papers are the following: The value of mineral variation in sediments as criteria for the recognition of particular rocks and for geologic age determinations; The limits of age determinations by this method; The value of mineral assemblages for purposes of correlation; Sediments as sources of information on paleogeography, and past climates; Sediments as sources of information on the nature of source rocks; Sediments as sources of information on diastrophic movements in areas of source rocks; Sediments as sources of information on the history of metamorphic rock masses. The discussion does not include many topics usually included in the general field of sedimentation, but is restricted to petrographic aspects of the subject.

The successful use of minerals in recognizing particular horizons and in correlation depends upon distinctive groups of minerals, peculiar varieties as well as species, and the relative abundance of the constituent minerals. These conditions are best developed in sediments which have been derived from different sources than overlying or underlying sediments. Distinctive differences are not as common in sediments which have been derived from a re-working of the older sediments in the same region. The English geologists, apparently, have been fairly successful in this work. It is possible that the absence of many examples of positive results in America is due to the comparatively small number of investigations which have been carried on and to the lack of detailed information concerning the mineralogical characters of our sediments over wide areas.

A chapter on authigenic minerals is of especial interest. Some forty-three minerals are now listed, including some which are rather surprising, such as rutile, titanite, garnet, feldspar, tourmaline, and staurolite. A chapter on the mineral composition of the clays presents a valuable summary of our present knowledge of these minerals. The importance of the work of Ross, Kerr, and other Americans who have recently contributed to this subject, is recognized.

The abstracts include French, Italian, German, Russian, Belgian, and Dutch papers, as well as those in English. The greater number of papers are those in which sediments are described in detail, in which correlation by minerals is attempted, or in which techniques are described. The abstracts appear to be adequate and with the very complete indexes should prove extremely serviceable.

This book is a valuable contribution in its field. It really is the first attempt at a general evaluation of the work, done up to date, in sedimentary petrology, especially from the viewpoint of correlation by means of minerals. It is evident that, while many difficulties and problems still remain, this type of work, in the future, will yield increasing information along certain lines. The abstracts are very valuable to workers who may or may not have access to large libraries. Professor Boswell suggests that the abstracts be continued in the Journal of Sedimentary Petrology. This would be a valuable source of information to many working in this field.

JOHN T. LONSDALE

NEW MINERAL NAMES

Hydroromeite

G. NATTA AND M. BACCAREDDA: Tetrossido di antimonio e antimoniat. Struttura cristallina dell' antimoniato di antimonile (tetrossido di antimonio), suo isomorfismo con i piroantimoniat di piombo e di calcio ed esame röntgenografico delle ocre di antimonio (Cervantite, Stibiconite) e degli antimoniat idrati di calcio (Idroromeite) e di piombo (Bindheimite). *Zeit. Krys.*, **85**, pp. 271-296, 1933. With German summary.

CHEMICAL PROPERTIES: A hydrous calcium antimonate: $2-3 \text{ CaO} \cdot 2 \text{ Sb}_2\text{O}_5 \cdot 6-8 \text{ H}_2\text{O}$. Analyses: From Villafranca, Galicia, Spain— H_2O 13.48, Sb_2O_5 62.90, Fe_2O_3 1.98, CaO 19.19, CO_2 3.33. From Higuera, Cordoba, Spain— H_2O 12.27, Sb_2O_5 70.01, Fe_2O_3 1.50, CaO 14.38.

CRYSTALLOGRAPHICAL PROPERTIES: Cubic. Space group O_h^{7-} . $a = 10.25 \text{ \AA}$.

PHYSICAL PROPERTIES: Villafranca—Color pale yellow to clear brown. Sp. Gr. = 3.50. Hd. = 3.5. Higuera—Color grayish yellow to canary yellow. Sp. Gr. = 3.66. Hd. = 5.

OCCURRENCE: The mineral from Villafranca results from the alteration of stibnite and is often pseudomorphous after it.

DISCUSSION: From a comparison of the powder photographs it is concluded that this mineral is isomorphous with bindheimite and with stibiconite. Powder photographs of this mineral before and after dehydration are the same as those for romeite.

W. F. FOSHAG

Portlandite

C. E. TILLEY: Portlandite, a new mineral from Scawt Hill, Co. Antrim. *Mineral. Mag.*, **23**, No. 142, pp. 419-420, 1933.

NAME: From Portland cement in view of its occurrence as a common product of hydration of Portland cement.

CHEMICAL PROPERTIES: Calcium hydroxide, $\text{Ca}(\text{OH})_2$. Microchemical tests show abundant calcium and in the closed tube gives reaction for water. The residue treated with AgNO_3 solution turns brownish-black. Slowly soluble in water; completely soluble in weak hydrochloric acid.

CRYSTALLOGRAPHICAL PROPERTIES: Hexagonal, in plates. Cleavage basal, perfect. $a = 3.64 \pm 0.10 \text{ \AA}$, $c = 4.85 \pm 0.10 \text{ \AA}$.

PHYSICAL PROPERTIES: Colorless. Luster on the plates pearly. Sectile and cleavage plates flexible. Hd.=2. Sp. Gr.=2.23.

Uniaxial, negative. $\omega = 1.575$, $\epsilon = 1.547$.

OCCURRENCE: Found with awillite in larnite-spurrite rocks at the contact zone at Scawt Hill. Results from the hydration of these calcium orthosilicates.

W. F. F.

Saleite

J. THOREAU AND J. F. VAES: La Saléite, Nouveau Mineral Uranifere. *Bull. Soc. Belg. Geol.*, **42**, pp. 96-99, 1932.

NAME: In honor of A. Salée.

CHEMICAL PROPERTIES: A hydrous phosphate of magnesium and uranium: $\text{MgO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 8\text{H}_2\text{O}$. Analysis (by M. Mollet, on about 400 mgs.) UO_3 64.70, P_2O_5 14.58, MgO 5.06, H_2O 16.64, Insol. 2.79; total 103.77.

CRYSTALLOGRAPHICAL PROPERTIES: Orthorhombic, pseudotetragonal. Habit square plates. Forms (001), (100), (010), also (120), (210). The crystals are twinned so as to show four quadrants with optic axes at right angles. Cleavage (001), perfect.

PHYSICAL AND OPTICAL PROPERTIES: Color lemon yellow. Hd.=2-3. Sp. Gr. a little less than 3.3.

Biaxial negative. $2V = 61^\circ$. Dispersion marked $r > v$. $\alpha = 1.559$, $\beta = 1.570$, $\gamma = 1.574$.

OCCURRENCE: Found intergrown in parallel position with torbernite and associated with other uranium phosphates on specimens from Chinkolobwe, Katanga. It is the magnesium analogue of autunite.

W. F. F.

Alumo-Chalcosiderite

A. JAHN: Alumo-Chalkosiderit, ein Neues Mineral vom Schneckenstein i. Vogtland, *Mitt. Vogtlandischen Gesell. Naturf.*, No. 8, p. 1, 1933.

CHEMICAL PROPERTIES: A hydrous phosphate of copper, iron and alumina, intermediate between chalcosiderite and turquoise, $\text{CuAl}_2\text{Fe}_4(\text{PO}_4)_4(\text{OH})_8 \cdot 5\text{H}_2\text{O}$. Analysis: CuO 6.82, Fe_2O_3 34.26, Al_2O_3 10.45, P_2O_5 33.82, CaO 0.87, H_2O 13.7. Sum 99.92.

PHYSICAL PROPERTIES: Color deep grass to bluish green. Streak, pale green. Sp. Gr.=3.0. Hd.=4½. Fracture uneven to conchoidal.

OCCURRENCE: Found as small crystalline balls or crusts on quartz and topaz crystals or on lithomarge often associated with pharmacosiderite at Schneckenstein, Vogtland.

W. F. F.

NEW DATA

Kolbeckite

H. THURNWALD AND A. A. BENEDETTI PICHLER: Gravimetric analysis of Beryllium Silicate Rocks. *Mikrochemie*, **9**, 200-220, 1932.

A microanalysis of a single blue crystal weighing 27 mgs. gave the following results: SiO_2 9.25, Al_2O_3 21.35, Fe_2O_3 0.29, BeO 8.74, CaO 3.22, P_2O_5 33.8, H_2O 23.45. Total 100.10.

W. F. F.